Sensitivity of agrobiocenoses components to ionizing radiation

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Abstract: To estimate effects of ionizing radiation on cenosis components, of great importance is characterization of the acting factor, exposure conditions and peculiar features of the development of living organisms. Different components of agricultural ecological systems show great variability in resistance to radiation. To understand agrobiocenotic consequences of radioactive contamination of agricultural lands, one needs to take into account effects arising not only in the moment of exposure but also later at various stages of the development, as well as during the conventional agricultural practice. The lack of significant differences was experimentally demonstrated in the rate of development of the natural population of Colorado beetle collected on fields in the Bryansk region with various contamination density for ^{137}Cs (up to 1.2 MBq/m^2) while sensitivity to insecticides of different chemical groups was the same. It has been found that factors defining infection of wheat plants by *Puccinia graminis tritici* are time from plant inoculation to exposure, dose of irradiation, air temperature and genetically determined resistance of plants to phytopathogen infection.

1. INTRODUCTION

A determining factor in assessing effects of anthropogenic contamination on agroecosystems is the content of pollutants in plants. However, this information can be indirectly extrapolated to the ecological level of the exposure impacts. During the intensive radioactive contamination of the agricultural land caused by anthropogenic accidents harmfulness of phytophags and phytopathogens in agrobiocenoses persists. [1, 2]. To ensure sustainable functioning of agrocenoses, of great importance is to reduce the anthropogenic burden based on harmonization of agricultural production and maintenance of the environmental safety. If we consider the mechanisms of ecosystem homeostasis at the level of an important component such as entomo- or pathocomplex, the minimization of both direct and indirect effects of ionizing radiations must manifest itself as changes in the microevolutionary processes expressed in the intensity of population development or changes in the physiological characteristics [3, 4].

2. MATERIALS

The target of the study were insects of natural and laboratory populations. Colorado beetles *(Leptinotarsa decemlineata Say)* were kept in conditions defined by the standard methodologies at the optimal temperature, humidity and photoperiod duration. The source of irradiation was the γ-device "GUR-120" (^{60}Co), doses of 0,5 - 50 Gy. The index LD_{50} was used to estimate ionizing radiation effects on the viability of insects.
Populations of Colorado beetles living for a long (18 years) time in conditions of agricultural land contaminated by radionuclides of the Chernobyl origin were studied on farms in the Bryansk region of Russia. Insects were collected on potato plants with the soil contamination density by ^{137}Cs (3- and 24-fold variations): 1.2 MBq/m^2; 0.4 MBq/m^2 and 0.05 MBq/m^2.
Wheat in the germination phase was irradiated with the mobile β-device "Penal" charged with LSI–10 (^{90}Sr -^{90}Y) at doses of 5 to 50 Gy. The plant-source distance was 30 cm, error of dose measurement was within 15%.
Plant inoculation with uredospores of *Puccinia graminis tritici Eriks. et Henn.* (strain 1K, uredospore burden – 5 mg/m^2) followed the common methodology.

3. RESULTS

3.1. Radiosensitivity and post-radiation effects in insects

Radioresistance of Colorado beetle in ontogenesis varied considerably. The embryonic period was characterized by the maximal radiosensitivity: early in the development LD_{50} was 8.5 Gy, within 48 h – 19.7 Gy and within 72 h – 35.5 Gy. LD_{50} for larvae of the first age was close to 40 Gy (36.8-40.2). The imago stage proved to be most resistant to radiation - about 50 Gy (46.7-52.5) [5]. Increased radiosensitivity (y) embryos Colorado potato beetle 24 - 72-h of development (x) is the linear dependence described by the equation: $y = 0.5625 x +5.7667$ (R^2 = 0,9904) (Fig. 1a).
The high LD_{50} value in adult insects predetermined their ability to survive in varying environmental conditions. In the course of ontogeny, in general, repeated set for the embryos of Colorado potato beetle patterns - increasing sensitivity with increasing age of insects (embryo-larvae-adult) (Fig. 1b). Development of radiation effects is closely connected with processes of active division of cells, since dividing cells are more radiosensitive to ionizing radiation [6]. When insects change from one phase of metamorphosis to another their physiological-biochemical state also changes: changes occur in oxygen consumption, enzymatic activity of the oxidation-reduction system, lipid exchange enzymes. Exposure to radiation also causes changes in the values of gas exchange, activity of lipase, catalase, succinate dehydrogenase and cytochrome oxydase [7].

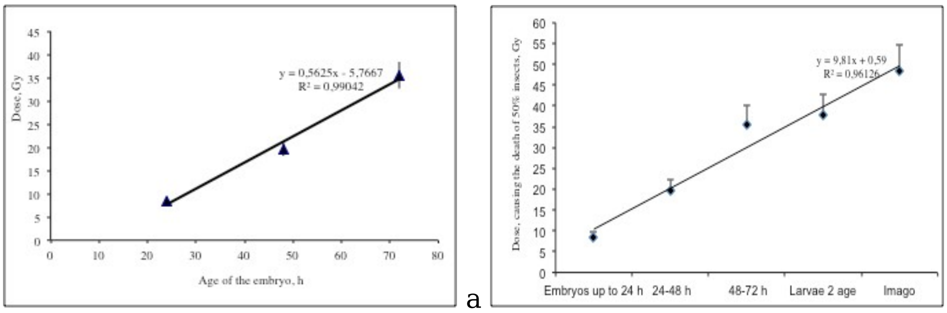

Figure 1. Effects of irradiation on Colorado potato beetle: a) embryos, b) embryos-adult.

The period of development of embryos (age 24-48 h) irradiated at doses of 8 to 20 Gy up to the imago stage increased by 4-7 days and irradiation of the imago insects (5 and 10 Gy) on the contrary reduced the life period by 10-20 days compared to the control.
The insects collected in the area of maximal ^{137}Cs contamination, 1.2 MBq/m^2, and exposed for a long time to chronic low-level radiation [8] needed much less time to complete the larval stage than beetles from other sites (Fig. 2). Noting that the growth curve did not depend on the dose irradiation: not different between the highest and lowest doses. No morphological changes were observed, except for those registered in the first group of morphotypes, morph 3.

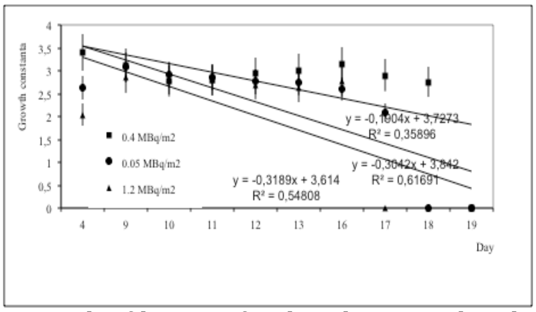

Figure 2. The constant growth of larvae of Colorado potato beetle.

Despite the reported phonologic deviations, no proportional changes have been found in the sensitivity of natural population of Colorado beetle to insecticides of various classes of chemical compounds (organophosphates, pyrethroids, neonicotinoids, phypronil, etc.) depending on the density of radioactive contamination and location. For the second age larvae (independent of ^{137}Cs contamination density, 1.2 … 0,05 MBq/m^2) most toxic were the drugs of a new generation (acting agent - a. a. – phypronil). The imago beetles proved to be more resistant to insecticides of the pyrethroid group (acting agents – permethrin and cypermethrin). Differences in cypermethrin sensitivity in beetles collected from plots with different contamination density were significant at $p<0.01$, however, direct proportional relationship between ^{137}Cs activity and mean insecticide concentrations (mcg a.s./ml solution) causing death of 50% of individuals (MC_{50}) was not found. Sensitivity to insecticides in Colorado beetles is connected with complex changes in the enzymatic activities of the systems. We have found high activity of oxidative enzymes (monophenolmonooxygenase) in beetles of the populations from areas with the elevated radiation background [8].
The mechanisms of living organisms responses to acute and chronic irradiation at low doses have their specific features. Therefore, for the populations of

insects-phytophages exposed to ionizing radiation (ChNPP exclusion zone) and untreated (for several generations) with pesticides, both increase and decrease in the insecticide sensitivity might be expected. Previously we have shown [9] that by the MC_{50} value the most sensitive to malation was the population of *Schizaphis gramina Rond* collected from the plots with the minimal radionuclide density (3.3 MBq/m^2). Corn aphids inhabiting the plots where the contamination levels were 4-10 times higher (33.9±0.07; 15.9±0.09 MBq/m^2) proved to be more resistant to the pesticide, and the sensitivity tended to increase with increase in the level of radioactive contamination of the test sites in the exclusion zone. On the contrary, with respect to a synthetic pyrethroid, intestinal insecticide, most sensitive were insects collected on plots with ^{137}Cs activity of 33.9 MBq/m^2. No regularities were found in the sensitivity development in cereal thrips (*Haplothrips tritici Kurd.*) to the given pesticides as a function of radionuclide contamination density.
Results from a model trial with corn aphids exposed to doses of 5, 25 and 50 Gy and its progeny demonstrate increase in insect resistance to the insecticide pyrimiphosmethyl (500 g/l) (Table 1).

Table 1. Toxicity of pyrimiphosmethyl for progeny of irradiated aphids.

Parameter	Dose, Gy			
	0	5	25	50
MC_{50} (a.a. , *10^{-4})	0,13	0,44	0,90	0,29
MC_{95} (a.a., *10^{-4})	0,41	0,87	17,00	1,20
MC_{50}/MC_{50} treated/untreated	-	3,40	6.90	2,20
MC_{95}/MC_{95} treated/untreated	-	2,10	41,50	2,90

This is especially pronounced for offsprings of arthropods irradiated at 25 Gy. The population became more tolerant: 6.9 times by the MC_{50} value and 41.5 times by theMC_{95} value.

3.2. Vulnerability of wheat to stem rust

It is known that development of stem rust (*Puccinia graminis tritici Eriks. et Henn.)* on wheat plants during the vegetation period is a series of successive transient infections. The more favorable for reinfection are the conditions, the higher is the harmful effect of a pathogen. We have found [2] that the infection level of wheat plants of two cultivars contrast in the sensitivity to pathogen (Eagle– spring wheat, resistant cultivar and Transfer – winter wheat, vulnerable cultivar) was determined by the time from inoculation to exposure and dose (Table 2).

Table 2. The levels of infestation of wheat varieties with different sensibility to stem rust (first leaf) at the optimum temperature.

The time from infection to exposure,	Dose, Gy				
	Blank (0)	5	15	30	50

day					
Eagl					
0	20,1	12,5	35,9	48,6	1,33
2	20,1	20,9	17,4	11,5	17,7
Transfer					
0	64,7	61,3	71,5	54,3	9,4
2	64,7	56,1	69,2	67,4	36,6

With the Eagle cultivar as an example, we have found that irradiation at a dose of 15 Gy at the moment of infection penetration caused more severe damage to plants compared to the variant where plants were exposed to radiation 2 days after the infection. On the contrary, dose increase to 50 Gy resulted in reduced level of infection. It should be noted that treatment at the same dose immediately after infestation of the sensitive cultivar Transfer also reduced the level of wheat infection. In this case irradiation of wheat varying in its sensitivity to pathogens at different times after inoculation did not produce significant effect on the duration of the pathogen incubation period (the observed deviations did not exceed 24 hours) and the type of Eagle and Transfer cultivars response to *P. graminis*.

The extent of injury of wheat cultivars varying in resistance to the pathogen depended on the time between the inoculation and irradiation, dose of irradiation and genetically determined resistance of plants. Changes in the injury level in plants contrast in their resistance to pathogen infection (cultivars of spring and winter wheat) depending on the sequence of irradiation and infestation are not connected with the loss of some virulence of the pathogen itself due to irradiation but are the result of the interaction of the pathogen with the host plant weakened due to the radiation effects on the metabolic processes.

4. CONCLUSION

One of the manifestations of post-radiation responses is variation in the rate of insect development which can influence the processes of population formation. A study of this phenomenon in insects-phytophags exposed to radiation is of great practical importance, since the increase in the period of infestant development can break the seasonal cycle and part of the population won’t have time to complete the development and will die. Supposing the policy of application of the countermeasures to protect potato fields from hazardous organisms on farms located in areas with different contamination density after the Chernobyl accident is the same (the use of insecticides of the same groups of chemical compounds), it can be inferred based on the data derived that the radiation factor have not produced effects on the formation of resistance in Colorado beetles to insecticides, and the reported changes mainly reflect the non-specific adaptation of organism to environmental conditions.

Analysis of the results from studying the wheat sensitivity to stem rust in the conditions of separate or combined irradiation of the cenosis components suggests that treatment of plants at doses of 5 to 50 Gy had mediated influence on the activity of *Puccinia graminis tritici*, without modifying the type of infection and length of the pathogen incubation period.

Changes in the extent of infection in wheat plants varying in the resistance to stem rust are unlikely connected with the loss of some virulence in the pathogen

itself under the influence of irradiation but are a result of interaction between the pathogen and plant affected by radiation.
When evaluating biological effects of irradiation of the components of agrocenoses and predicting losses of crop productivity of great importance may be not only the cultivar sensitivity of plants to radiation but also plant resistance to biotic and abiotic factors which can modify the responses.

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